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PERCENTAGE REINFORCEMENT AND CHOICE

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Pigeons responded on identical concurrent variable-interval schedules (choice phase), producing outcomes of either periodic reinforcement schedules always terminating in reinforcement (reliable schedule) or otherwise identical schedules providing reinforcement on only a percentage of instances (percentage reinforcement schedule). Comparisons of this type constituted two assessments of the generality of preference for percentage reinforcement reported by Kendall (1974). In a third set of conditions, a reliable schedule was pitted against a percentage reinforcement schedule in which the more negative outcome was a leaner schedule of reinforcement (rather than nonreinforcement, as in the other two conditions). In all three types of conditions, the schedule providing the higher rate of reinforcement was preferred. Results from a subsequent manipulation suggest that Kendall's contrasting results may have depended on the fact that the stimuli in his choice phase (unlit keys) were physically identical to the stimulus correlated with the nonchosen outcome in his outcome phase.

Key words: percentage reinforcement, choice, rate of reinforcement, conditioned reinforcement, concurrent-chains schedule, response-independent schedule, multiple schedule, key peck, pigeons

Kendall (1974) reported that pigeons preferred a schedule of reinforcement that provided food delivery intermittently to one providing twice the rate of food delivery. His results are not readily incorporated within quantitative models of choice behavior. Specifically, Kendall compared two periodic schedules, 15 sec in duration, which differed in that one reliably ended in reinforcement (probability of reinforcement, $p = 1.0$) while the other ended in reinforcement half the time ($p = .5$) and otherwise ended in blackout. Kendall found preference for the reliable schedule only when differential stimuli were not correlated with the intermittent outcomes, i.e., impending reinforcement or blackout. When stimuli were correlated with the intermittent outcomes, pigeons preferred the intermittent outcome, even though this outcome provided only half the rate of reinforcement available during the reliable outcome.

Since the latter result may seriously limit the generality of quantitative models of choice (e.g., de Villiers, 1977; Fantino, 1977), it is important to assess how general preference for intermittent reinforcement may be. Kendall (1974) used a variant of the concurrent-chains procedure (Fantino, 1977) in which both stimuli in the choice phase (initial links) were unlit keys as was the stimulus associated with the nonchoice outcome in the outcome phase (terminal links). One question addressed by the present study is whether or not similar results can be obtained with a standard concurrent-chains procedure, in which the initial-link stimuli are lit keys and do not recur in the terminal links. Thus, two sets of conditions in the present experiment assess preference for reliable vs. intermittent schedules with more conventional concurrent-chains procedures.

In the most typical concurrent-chains procedure, all outcomes end in reinforcement. Indeed, the delay-reduction hypothesis (Fantino, 1977) applies only to such cases. Thus, in one set of conditions the more negative outcome in the "intermittent" schedule is a schedule of reinforcement with a low rate of reinforcement (instead of blackout and nonreinforcement, used by Kendall). The second set of conditions employs a conventional concurrent-chains schedule but is more similar to that used in Kendall's study in that the more nega-

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tive outcome in the intermittent schedule is a blackout and nonreinforcement. If preference for intermittent reinforcement were obtained in both conditions, the generality of Kendall's results would be greatly enhanced and the implications for quantitative models of choice profound. If such preference occurred only when the more negative outcome on the intermittent schedule was nonreinforcement, however, it would appear that the generality of Kendall's results was more limited and the implications for choice theories more circumscribed. Finally, if preference were obtained in neither case, the generality of Kendall's results would appear limited to the type of unconventional concurrent-chains procedure he employed. In that event, of course, implications for quantitative models of choice would be minimal. In order to better assess this possibility, a third set of conditions attempted to replicate Kendall's procedure as closely as possible.

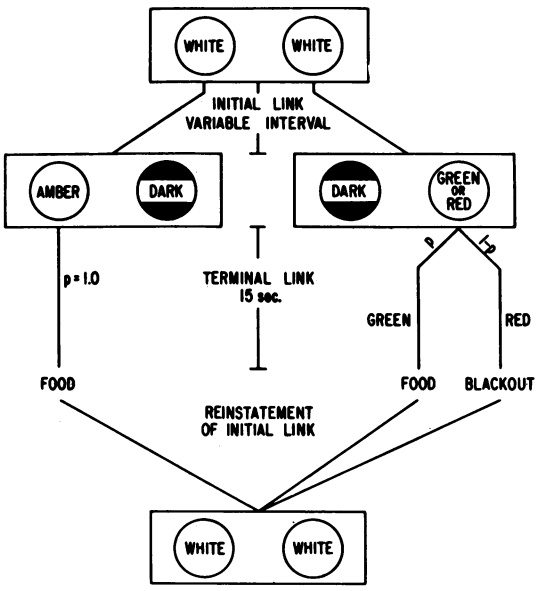

Fig. 1. The sequence of events in the concurrent-chains procedure used in the percentage reinforcement condition. Circles within the boxes represent the stimuli on concurrently available response keys. The sequence on the left key always ends in food delivery. The sequence on the right key ends in either food delivery or blackout.

METHOD

Subjects

Thirteen adult male White Carneaux pigeons were maintained at approximately 80% of their free-feeding weights. Three (4251, 4835, and 6392) had served in previous two-key procedures. The remaining subjects were experimentally naive. The birds were weighed after each experimental session and fed measured amounts of food to maintain weight levels. Water and grit were available in the home cages.

Apparatus

For the two sets of conditions employing the standard concurrent-chains procedure, a standard two-key operant conditioning chamber was used. The two translucent response keys were mounted 8.6 cm apart and 23 cm above the floor, each requiring a minimal force of about .15 *N* to be activated. Pecks on the response keys produced a light flicker of .1 sec. Keys could be transilluminated with various colors. A solenoid-operated grain hopper was centrally located below the keys and provided 3.5 sec access to mixed grain. General chamber illumination was provided except during the operation of the hopper or blackout. White noise was continuously present. Standard electromechanical scheduling equipment was located in an adjacent room.

A cylindrical chamber, 36 cm in height and 33 cm in diameter, was used for the more direct replication of Kendall's procedure. Three response keys were mounted 24 cm above the floor and could be transilluminated with lights of various colors. Only the two side keys were used, and tape covered the middle one. A minimum force of about .13 *N* was required to activate the keys. A solenoid-operated hopper was located 16 cm below the middle key and, when operated, allowed 4 sec access to Purina Pigeon Chow. General chamber illumination was provided except during the operation of the hopper or blackout. White noise was continuously present. Scheduling of experimental events and data recording were accomplished with a PDP-8E computer, under control of the Systol operant laboratory software developed in our laboratory.

Procedure

A modified autoshaping technique (Brown & Jenkins, 1968) was used to train Birds 61, 62, 64, and 66 to peck lighted keys. Birds 2396,

2675, 3405, 1875, 2080, and 0813 were trained in a similar procedure to peck dark keys. Once reliable responding was established, the birds were placed on concurrent-chains schedules. In this procedure, exemplified in Figure 1, pigeons respond on two concurrently available keys, each of which is illuminated with the stimulus associated with the initial link of one chain. Responses on each key occasionally produce the stimulus correlated with the terminal link of the chain on that key. Once a terminal link is entered on a key, responding is effective only on that key until the associated schedule of reinforcement is completed. Following the completion of the terminal link (with either reinforcement or blackout), the initial links are reinstated. Generally, the independent variable is the difference in conditions arranged during the terminal links. The relative rate of responding in the initial links (the rate of responding in one initial link divided by the sum of the rates of responding in each initial link) is the measure of preference. In percentage outcome procedures, each chain may have more than one possible terminal-link condition. These are randomly alternated with a fixed probability of occurrence.

In all conditions, the initial links were independently programmed variable-interval (VI) schedules. When a terminal-link entry was scheduled by either VI tape, it stopped, and the other tape continued to operate. Terminal-link entry stopped both initial-link tapes. Intervals were derived from the distribution suggested by Fleshler and Hoffman (1962).

The comparisons examined are shown in Table 1. Except for the .50 vs. .50 baseline comparison, all continued for a minimum of 15 sessions and until a stability criterion had been satisfied. After 15 sessions, the choice proportions, relative rates of responding in the initial links, for the previous 9 sessions were divided into blocks of 3 sessions. Performance was considered stable when the means of the three blocks neither differed by more than $\pm.05$ nor exhibited a trend, i.e., neither $\bar{X}_1>\bar{X}_2>\bar{X}_3$ nor $\bar{X}_1<\bar{X}_2<\bar{X}_3$. For each comparison, following the achievement of stable responding on an initial determination, the schedules were reversed on the keys. Each subject was exposed to one of three sets of conditions, described below.

Percentage reinforcement: Birds 4251, 4835, and 6392 were exposed to VI 60-sec initial-link schedules and 15-sec terminal links with response-independent outcomes. Both keys were illuminated white in the initial links. The terminal-link outcome was either a 3.5-sec food delivery or a blackout (3.5 sec with all lights extinguished). Terminal-link entry was accomplished by the illumination of the operative key, as follows: left key, food outcome, amber; left key, blackout (BO) outcome, blue; right key, food outcome, green; and right key, BO outcome, red. The inoperative key was dark. Sessions continued for 100 outcomes and occurred 6 days a week.

Percentage delay: Birds 61, 62, 64, and 66 were placed on VI 60-sec initial-link schedules correlated with white keylights. Terminal links were either fixed-interval (FI) 10-sec or FI 60-sec response-dependent schedules with the probability of FI 10-sec noted in Table 1. The keylights during the terminal links were as follows: Left, FI 10-sec, amber; left, FI 60-sec, blue; right, FI 10-sec, green; and right, FI 60-sec, red. The inoperative key was unlit. In a final comparison, terminal links were either variable-interval (VI) 10-sec or VI 60-sec response-dependent schedules. Initial-link schedules and keylights were identical to those in the FI comparisons. Grain was presented at the completion of each terminal link. Sessions were continued for 75 grain presentations and occurred 6 days a week.

Kendall replication: Birds 2696, 2675, 3405, 1875, 2080, and 0813 were exposed to a concurrent-chains procedure more similar to that reported by Kendall (1974). The initial links were VI 20-sec schedules. Terminal links were 15 sec with response-independent outcomes. Initial link keys were unlit. The terminal links were correlated with the following keylights: left, food, white; left, BO, blue; right, food, green; and right, BO, red. The inoperative terminal link key was unlit. Any response to the lit terminal link key during the last 2 secs of a terminal link postponed the outcome by 2 sec. Responses in the initial links and to both the lit and unlit terminal link keys were recorded.

Examination of terminal-link responding during both the initial comparison and the reversal revealed responses to the dark inoperative key in the presence of the stimulus correlated with blackout. Responses to the inoperative key were present only in this terminal link. The stimulus on this key (the terminal

Table 1

Order of schedules, choice proportions for the outcome providing the higher rate of reinforcement, and the number of sessions to stability (in parentheses) for each schedule.

	Schedule			Subjects					
	Left chain		Right chain	4251	4835	6392			
Percentage Reinforcement	.50	vs	.50	.51(16)	.53(16)	.50(16)			
	.80	vs	.50	.60(25)	.61(25)	.67(25)			
	.50	vs	.80	.63(30)	.62(31)	.57(27)			
	1.0	vs	.50	.58(22)	.58(21)	.64(15)			
	.50	vs	1.0	.54(16)	.61(21)	.62(23)			
	1.0	vs	.75	.61(22)	.57(21)	.52(22)			
	.75	vs	1.0	.61(30)	.57(35)	.54(32)			
	1.0	vs	.25	.65(20)	.70(22)	.73(28)			
	.25	vs	1.0	.67(18)	.72(26)	.75(21)			
	1.0	vs	.50	.63(27)	.70(30)	.69(38)			
	.50	vs	1.0	.52(42)	.56(47)	.64(32)			
Percentage Delay				61	62	64	66		
	.50	vs	.50	.49(16)	.57(16)	.52(16)	.51(16)		
FI	1.0	vs	.50	.56(22)	.63(24)	.72(18)	.59(16)		
	.50	vs	1.0	.73(22)	.67(27)	.57(17)	.58(19)		
	1.0	vs	.90	.60(21)	.57(25)	.39(20)	.57(22)		
	.90	vs	1.0	.42(23)	.50(28)	.57(22)	.55(18)		
VI	1.0	vs	.50	.60(32)	.57(24)	.56(21)	.64(21)		
	.50	vs	1.0	.55(28)	.61(51)	.73(36)	.60(47)		
Kendall Replication				2696	2675	3405	1875	2080	0813
	1.0	vs	.50	.62(18)	.22(21)	.46(19)	.54(20)	.57(22)	.52(22)
	.50	vs	1.0	.43(15)	.67(19)	.66(16)	.38(16)	.52(16)	.64(15)
Inoperative Key Lit	1.0	vs	.50	.57(18)	.47(18)	.49(16)	.59(18)	.71(15)	.48(18)
	.50	vs	1.0	.48(16)	.70(18)	.65(16)	.47(16)	.62(18)	.65(16)

link of which is always correlated with food) is identical (dark) whether it occurs during an inoperative terminal link or during the initial links. This equivalence may have functionally lengthened the initial-link intervals in the chain without blackouts (see Discussion). This may in turn have depressed preference for that key (e.g., Squires & Fantino, 1971), thereby producing apparent preference for intermittent (percentage) reinforcement. Thus, the next (third) comparison was a reversal of the prior comparison except that the inoperative terminal link was correlated with an amber keylight (distinct from the unlit keys of the initial links). This comparison was followed by a simple (position) reversal; again, the amber keylight was correlated with the inoperative terminal link. Sessions were continued for 50 food presentations and occurred 6 days a week.

RESULTS

The obtained durations of the initial and terminal links both closely approximated the scheduled durations. Choice proportions (relative rates of responding in the initial links), expressed in terms of the terminal-link outcome providing the higher rate of reinforcement, and the number of sessions to stability for each condition are shown in Table 1. The choice proportions are averaged over the last 5 sessions of each condition. For the baseline conditions (.50 vs. .50), choice proportions are expressed in terms of the right key. The results for each of the three types of conditions are summarized below.

Percentage reinforcement. In each comparison, all birds showed preference for the outcome providing the higher rate of reinforcement. For the three comparisons of percentage

and reliable ($p = 1.00$) reinforcement, the choice proportions tended to be successively higher as the rate of reinforcement on the percentage outcome schedule decreased. The exception was bird #4251, which showed greater preference in the 1.00 vs. .75 than in both 1.00 vs. .50 comparisons.

Percentage delay. All subjects in the 1.00 vs. .50 and reversal comparisons also preferred the outcome providing the higher rate of reinforcement. As might be expected in light of the nominal difference between the rates of reinforcement for the two outcomes in the 1.00 vs. .90 comparison, however, preference in this condition was inconsistent and variable.

Kendall replication. In the initial comparison and reversal, key bias appears to account for most of the variance. Averaging across the initial and reversal determinations, Birds 2696, 3405, 2080, and 0813 showed slight preference for the outcome providing the higher rate of reinforcement, and Birds 2675 and 1875 for the outcome providing percentage reinforcement. Responding to the operative key during the last 2 secs of a terminal link was minimal, and the obtained terminal link duration closely approximated the schedule duration.

The illumination of the inoperative terminal link key resulted in increased choice proportions for most of the subjects. Moreover, averaging over the initial and reversal determinations, all birds now preferred the chain with the higher rate of reinforcement, just as the seven other subjects had in the other conditions. Preferences tended to be smaller in the present condition, however.

DISCUSSION

The present results generally failed to extend Kendall's (1974) finding with a modified concurrent-chains procedure—that an outcome providing percentage reinforcement is preferred to one always providing reinforcement. Kendall noted that one interpretation of his results is that a conditioned reinforcer (the stimulus associated with the terminal link) may be stronger if it occurs in a local context which includes stimuli correlated with nonreinforcement. The present results, however, suggest that when a conventional concurrent-chains procedure is employed, the stronger conditioned reinforcer is the one associated with the higher rate of primary reinforcement. This result was obtained when the more negative outcome was nonreinforcement ("percentage reinforcement" condition) or a relatively low rate of reinforcement ("percentage delay" condition). Thus, Kendall's results do not appear to apply to conventional concurrent-chains procedures, at least for the values employed in the present study. We believed that any effects of relatively negative outcomes are likely to be greatest when they occur relatively infrequently and when differences in rates of primary reinforcement are minimal. For this reason, we included one comparison in which the difference in relative rate of reinforcement was minimal (.90 vs. 1.0 in the percentage delay condition, corresponding to a relative rate of reinforcement less than .52) in which the occasional, presumably contrasting, effects of the more negative outcome might be more likely to affect preference. Reliable preference for the percentage reinforcement outcome was not obtained even in this condition, however (indeed, the mean preference, averaged over subjects and reversals was .52 for the outcome providing the higher rate of reinforcement).

When Kendall's study was replicated as closely as possible (i.e., as closely as his procedure section and a personal communication from him permitted) using his variant of the concurrent-chains procedure, clear preference for percentage reinforcement again failed to occur. In this case, however, preference also failed to develop for the outcome providing the higher rate of reinforcement. These results, therefore, are troublesome for quantitative models of choice (e.g., de Villiers, 1977; Fantino, 1977). This procedure differs in several ways from more typical concurrent-chains procedures in that the keys are dark during the initial links; the inoperative terminal link key (i.e., that associated with the unchosen outcome) is physically identical to the key during the initial link; the initial link durations were short (VI 20-sec); responses to the lit terminal-link key postponed the outcome; reinforcement did not occur during each outcome. One or more of these factors might account for the different results obtained in the Kendall replication, on the one hand, and in the percentage delay portion of the study, on the other. The one difference that appeared most profitable to investigate was that involving the physical equivalence of the initial-link stimulus and that of the inoperative terminal link. Presum-

ably, in the terminal links preceding food delivery, responding was likely to be exclusive to the stimulus correlated with food, i.e., the subject would not attend to the inoperative key. Indeed, responding to the dark (inoperative) terminal-link stimulus occurred only when the concurrent stimulus was correlated with blackout. Responding to a dark key in the terminal links was therefore limited to the key correlated with the chain providing the *higher* rate of reinforcement. To the extent that a subject generalized between the dark terminal-link and dark-initial link stimuli in this chain, the functional length of this initial link would have increased. Such an increase should have enhanced choice for the alternative, percentage reinforcement, outcome (Squires & Fantino, 1971). This suspicion was strengthened in the final portion of the study in which the inoperative terminal-link key was made distinct from the initial links. In this condition, each of six pigeons now preferred the outcome providing the higher rate of reinforcement.

In conclusion, none of the results in the present set of studies supports the notion that a schedule of intermittent reinforcement is preferred to one providing reinforcement on every trial. Instead, the results are consistent with the general principle that subjects will choose outcomes producing higher rates of reinforcement (e.g., de Villiers, 1977; Fantino, 1977; Herrnstein, 1961; Shimp, 1969).

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